2008-21-0005

Safe and Pleasurable Human Machine Interfaces for Automobile

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ABSTRACT

As a consequence of the integration of additional systems to support and entertain drivers and passengers the interactions with those systems become more and more time consuming and distracting. It is therefore a basic requirement for the design of Human-Machine-Interfaces to minimize the distraction from driving when interacting with those new assistance and entertainment systems. Whereas the safety is a Must-be for the design of HMI for automobiles the joy-of-use is an important aspect for the excitement of drivers. To fulfil the sometimes conflicting demands for safety and pleasure a human centred design approach for HMI design is needed.

INTRODUCTION

The increasing potentialities of vehicle electronics bring with it an increasing number of new systems to support but also to entertain the driver. In the new generation of cars, more and more advanced driver assistance systems (ADAS) appear which are able to support the driving activity. For example, ACC-systems (Adaptive Cruise control) regulate actively the speed and the distance to a lead vehicle in place of the driver. Lane assistance systems provide information for the driver that he is leaving his line and some systems correct actively the trajectory of the car. Navigation systems are indicating permanently to the driver the way he has to follow to reach his target. Further assistance systems are in the development phase, like crossing assistance or tiredness warnings.

But it is not only that systems with a clear relation to the primary or secondary driving task are entering today's vehicles. There are several systems for communication, information or entertainment that are within today's cars or on its way to application (e.g. internet based services for cars [1]).

All of those assistance or entertainment systems have an interface with the driver; more precisely the driver has to interact with all those assistance systems. The benefit, that the driver is supposed to gain with the usage of such assistance system, depends on the fitting between systems functionality and especially HMI design and the characteristics, abilities, needs and wishes of drivers.

The aim is to deliver the correct information, in an appropriate form at the correct time to the driver and to provide the driver with handling elements that support his physical characteristics.

Two difficulties are encountered at this level:

- A side effect of supporting driving activities with (semi-)autonomous systems is that the driver is put partially in a passive role. The difficulty is then, like with the introduction of automation in other human machine systems, the necessity for drivers to be able to override the system when it is necessary. This means that drivers although they are passive had to follow and understand the driving activities of the assistance system. In this context the need for an intuitive HMI design is obvious.

- The increasing number of assistance system, which are until now rarely coupled, provides drivers with an increasing number of information about the actual driving activities. For drivers this presents two difficulties: they have to collect further driving information in case they must override the system and they have to prioritize the information that they get from different assistance systems.

The risk of overloading drivers instead of supporting them is high and is very much dependent on drivers' capabilities, mentally and partially physically.

HUMAN CHARACTERISTICS FOR DRIVING

The basic relation between driver, vehicle and environment is shown in figure 1.

There are different approaches used to explain human information processing within this system model. One is based on the multiple resources model according to [2]. This model explains how it is possible for drivers to perform different tasks at the same time and it explains furthermore the limitations of the human multi-tasking.

A second model frequently used to explain different duration of task performances or mistakes that can be observed between different persons performing the same task or for one person performing the same task at different training levels. This model distinguishes three levels for human behaviour: skill-based level, rule-based level and knowledge-based level [3].

Actions that are performed at the skill-based level are highly automated and thus can be executed very fast and require only a small degree of attention. Examples of skill-based behaviour can be found mainly when drivers have to stabilize their vehicle on the road.

Actions at rule-based or knowledge-based level require a higher level of attention and a longer time for execution. Those actions require more cognitive resources from drivers which means that it is difficult to perform multiple tasks at rule-based level and even impossible to do more than one task at knowledge-based level.

For many drivers the use of most advanced driver assistance systems is a task performed at least at rule-based level. The usage is far from a high level of intuition and drivers have to learn several rules for interacting with those systems.

When being confronted with a new and unexpected situation of their assistance systems drivers sometimes switch to knowledge-based behaviour and that means their capabilities for performing the driving task with high quality are drastically decreased.

DISTRACTION- The consequence of performing too many tasks at the same time might be the distraction of drivers.

According to [4] distraction can be divided into four categories:

- Visual distraction (e.g. looking away from the roadway)
- Auditory distraction (e.g. responding to a ringing cell phone)
- Biomechanical distraction (e.g. manually adjusting the radio volume)
- Cognitive distraction (e.g. being lost in thought)

Thus the design of safe HMI for automotives should reduce the time of visual, auditory, biomechanical and cognitive distraction.

REACTION TIME- Interacting with many different HMI while driving has also an effect on drivers' reaction to suddenly appearing obstacles. In table 1 a summary of published data on human reaction times is listed [5].

Stretched reaction time in emergency braking situations	Mean 0.9 s Deviation 0.3 – 2.0 s	Johansson & Rumar, 1971
	All times < 2.5 s	Koppa et al., 1996
	Mean 0.7 s	ATZ, 1983
Factors influencing stretched reaction time	No influence attributable to gender, weather or traffic conditions	ATZ, 1983
	Stretched reaction time prolonged by 0.4 s if driver is not concentrating on the road.	ATZ, 1983
	Stretched reaction time cut by approx. 0.4 s if braking action of vehicle in front is accompanied by switched-on light.	Martin & Holding, no year
	Distance to next vehicle influences stretched reaction time, but vehicle speed does not.	Liebermann et al., 1995
	No clear influence from driver age, but younger drivers do attain shorter stretched reaction times in this study.	Lerner et al., 1995
	Older drivers need longer stretched reaction times than younger ones.	Wierwille, 1990 Broen & Chiang, 1996
	Significantly longer stretched reaction times if the driver is not concentrating on the road when the stimulus occurs.	Summala et al., 1998
	Purpose of journey, mental strain, nervous disease and drug consumption influence stretched reaction time.	Summala, 2000

Table 1: Summary of published data on human reaction times [5]

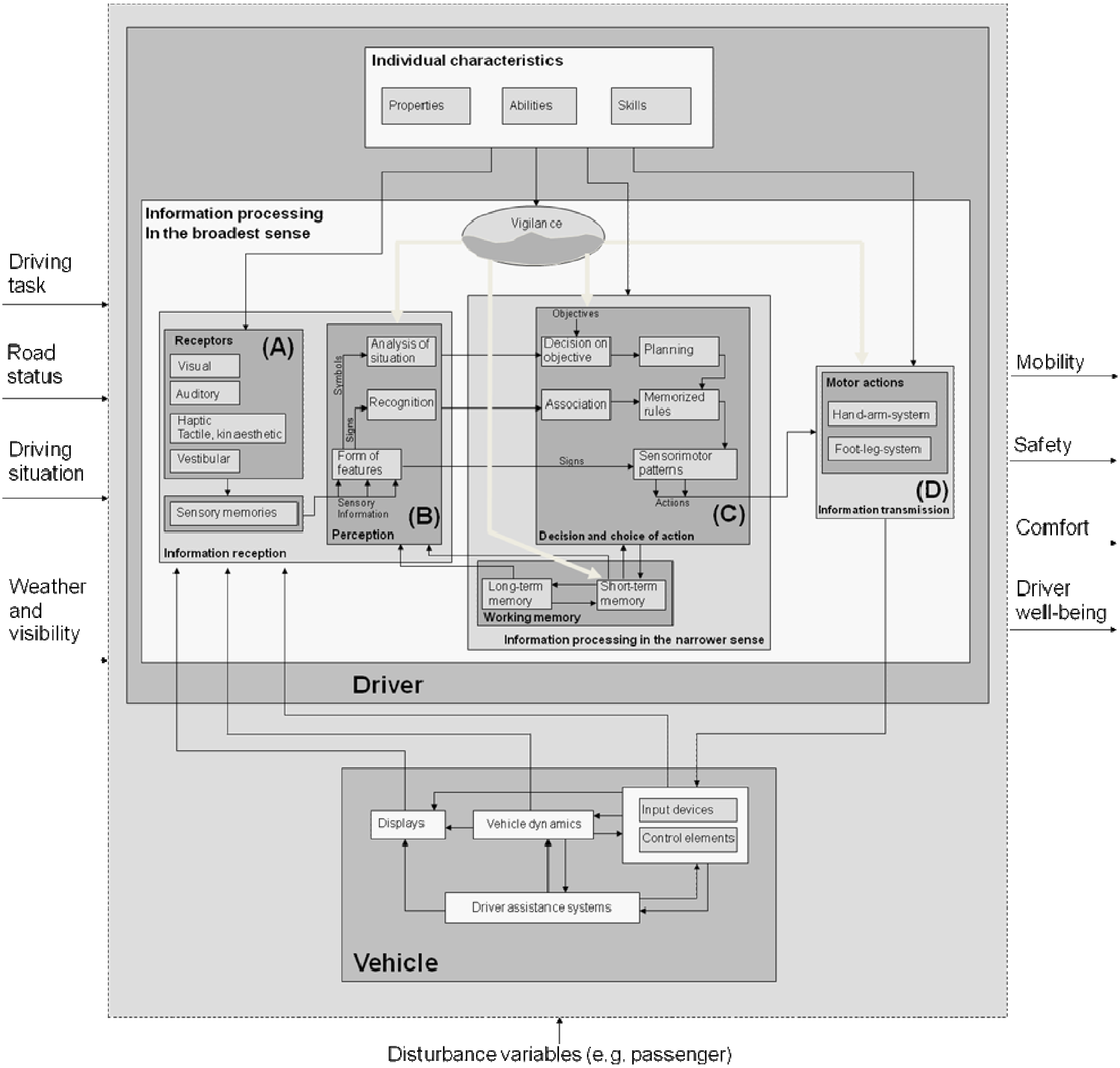

Figure 1: System model of driver-vehicle environment

ELDERLY DRIVERS- Because of the demographic development it is expected that especially elderly drivers will play an important role for the traffic of the future. So it is of interest to take especially the characteristics of elderly into concern when designing HMI for future automobiles.

Because of alterations of tissue in the eyes the visual capabilities of elderly persons are decreasing (e.g. lower static and dynamical visual acuity, higher risk for dazzling). Especially the reduction of the field of vision is critical for driving situations because the movement of relevant objects is seen first in the peripheral field of vision. So visual distraction is more risky for the elderly and thus should be avoided.

Also auditory and tactile perception might be negatively affected by the age of drivers. The sensorial memory is working less efficiently with increasing age. That means for example that acoustical information will be present only for a short period of time. Different visual stimuli can be captured and processed only to a small extent.

All the reduction in the sensorial processes makes it necessary to avoid an information overload when designing HMI for elderly drivers.

This “less is more” approach for HMI design is furthermore encouraged by the fact that elderly drivers have overall diminishing resources for attention. One effect of the attention deficit is that elderly drivers have less information from the environment for decision making compared to younger drivers. Here the adequate design of HMI might support the elderly in the process collecting an processing information.

PLEASURABLE INTERFACES

The human characteristics that had been described so far have to be considered when designing HMI for automobiles with a high priority on safety. But besides the high demand for safety when designing HMI for automobiles it should not be neglected that drivers want to have more than pure functionality when interacting with their car. “Driving remains emotional”, as it is described by Dr. Thomas Weber (Member of the Management Board of Daimler AG).

The fulfillment of the driving task in an adequate way, total control of the car even in difficult driving situations or to feel the direct contact between car and street can be described as possible stimulators for positive emotions while driving. Compared with this emotions derived from the primary driving task the use of HMI while driving is not suspicious to provoke positive emotions.

This might change in the future as driving experiences are more and more influenced by using different HMI while driving. So it seems to be useful to look at the already available knowledge with respect to design HMI that are joyful to use.

The following statement of Donald Norman, a psychologist concerned with human design problems, demonstrates clearly the need for a HMI design that pleases human emotions.

“Tools are meant to support serious, concentrated effort, in which the task is well specified and the approach relatively well understood, are best served by designs that emphasize function and minimize irrelevancies. Here the normal tensions of the situation are beneficial. The design should not get in the way; it must be carefully tailored for the task. … Use a pleasing design, one that looks good and feels – well –sexy, and the behavior seems to go along more smoothly, more easily, and better. Attractive things work better.” [6].
The challenge for pleasurable HMI design in automobiles is to bridge the gap between the demand for a reduced level of attention when using the interfaces and the wishes of drivers to be surprised by a new design of the HMI.

“Especially interface designers must identify ways to introduce novelty and surprise with their interfaces (and the behaviour of the software system) without sacrificing to much ergonomic quality (e.g. familarity). From this perspective the impact of hedonic quality on the appeal of a software system may be the rationale for introducing new interface elements (or even completely new metaphors) and to justify the risk of impaired ergonomic quality [7]"

Here is a list of design rules to be respected when designing pleasurable HMI [see 8, 9].

- Don’t think product, think experience
- Don’t think beauty in appearance, think beauty in interaction
- Don’t think ease of use, think enjoyment of experience
- Don’t think buttons, think rich actions
- Don’t think labels, think expressiveness and identity
- Metaphor sucks
- Don’t hide, don’t represent, show
- Don’t think affordance, think irresistibleness
- Hit me, touch me and I know how you feel
- Don’t think thinking, just do doing

STUDIES ON HMI DESIGN FOR VEHICLES

The studies that will be presented within this paper focus mainly on the HMI design for advanced driver assistance systems (ADAS). That is because the pure number of ADAS that had become part of even mass-market cars has increased over the last years. The functionality of ADAS can have a significant influence on the decision to buy a car. But it is not only the functionality of the ADAS that is decisive for the customer. It is how he or she gets into direct contact with the ADAS. And this direct contact is very much dominated by the design of the HMI for the ADAS.

The HMI design for most of the ADAS has a clear focus on safety aspects. Nevertheless there is also a relation to the concept joy-of-use in so far that an ADAS that requires the least amount of additional attention for its use and guarantees at the same time the highest amount of reliability will be highly accepted by drivers.

Referring to the Kano model of customer satisfaction [10] HMI design for ADAS has to fulfill recommendations on different levels.

Level 1: *Considering basic needs of driver*
e.g. high system reliability; low level of driver distraction

Level 2: *Enhancing the performance of drivers*
e.g. minimizing the risk for accidents; making driving less stressful; completion of drivers characteristics

Level 3: *Stimulating drivers enthusiasm*
e.g. coping of highly dangerous situations, enhancing drivers comfort; expansion of drivers characteristics

Following two research studies will be presented with a focus on the design of HMI for enhancing the performance of drivers (level 2). In the first case the a study with respect to the design of HMI for full speed adaptive cruise control will be presented. The second study refers to the design of night vision systems with pedestrian detection.

The aim of both ADAS is to improve the safety of the human-vehicle system. But at the same time driving should be made less stressfull (Full speed ACC) and drivers characteristics should be completed (night vision system).

HMI FOR FULL SPEED ACC- Latest versions for ACC systems have the ability to support the driver in conducting the car in longitudinal directions even in low speed range. Thus those full speed ACC systems can be used in traffic jams on motorways but also in inner city scenarios.

To know about the actual status of the ACC system is crucial for the drivers as they have to decide whether they have to override the actions proposed by the ACC system or whether they have to take the control back from the system.

A study with eight drivers experienced in using ACC systems was conducted at the Institute of Ergonomics of Darmstadt University of Technology to find out the advantages and disadvantages of different HMI design for full speed ACC systems.

The test persons had to drive a course of 62,4 km on public roads. The composition of the course is shown in the following table.

Type of Road	**Distance in km**	**ratio**
urban/city road	35,9	57,5%
country road	3,0	4,8%
federal road / motorway	23,5	37,7%
Total	62,4	100%

Table 2: Composition of test course for studies on full speed ACC

Generally it was detected that driver believes that the ACC will be able to manage the driving situation and it works effectively. So they used the full speed ACC whenever it was possible.

Nevertheless the use ratio of ACC-FSR decreases according to the road type: motorway, city road and urban roads (see figure 2). The driver only activates the system when he or she believes that the ACC will be able to manage the driving situation and it works effectively.

In the city drivers do not try to use the ACC system. Mostly it is due to the technical limits of the system.

For example: in a turn, the target vehicle is quickly lost. The ACC-system takes inappropriate decision due to the lack of information on the complete driving environment.

Furthermore there are differences in the activation and deactivation of the ACC system in different types of cars. The analysis of the subjective data shows that the information system about the ACC state is an important element that explains those results.

The presentation of information about ACC state on a head up display is a reason for a better understanding of the driving situation.

The preference for the head up display is strongly confirmed with the complementary questionnaire (see figure 3).

So an important result from the studies concerning the HMI design for a full speed ACC is the finding that the trust drivers have for the ACC system depends on the information they get about the actual status of the system. Furthermore it is not enough to provide the drivers with this information but the information must be presented in such a way that it is intuitively understandable. If this information is displayed with a technology that is well suited for presenting status information about ACC and this technology is still unusual in nowadays cars (like it is true for head up displays) it is more likely to stimulate drivers enthusiasm.

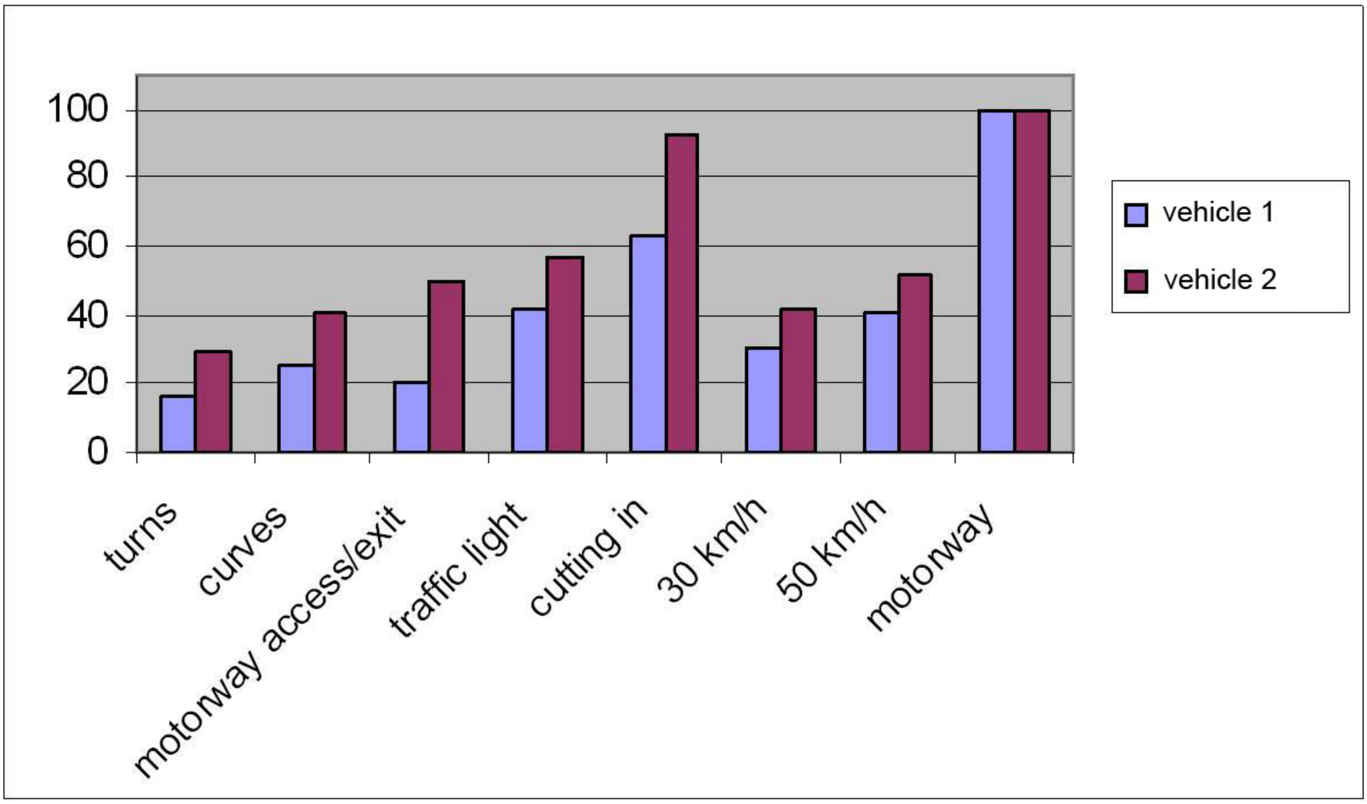

Figure 2: Number of situations during which the ACC-system was continuously activated compared to the global number of situations [%]: Normal use without interruption.

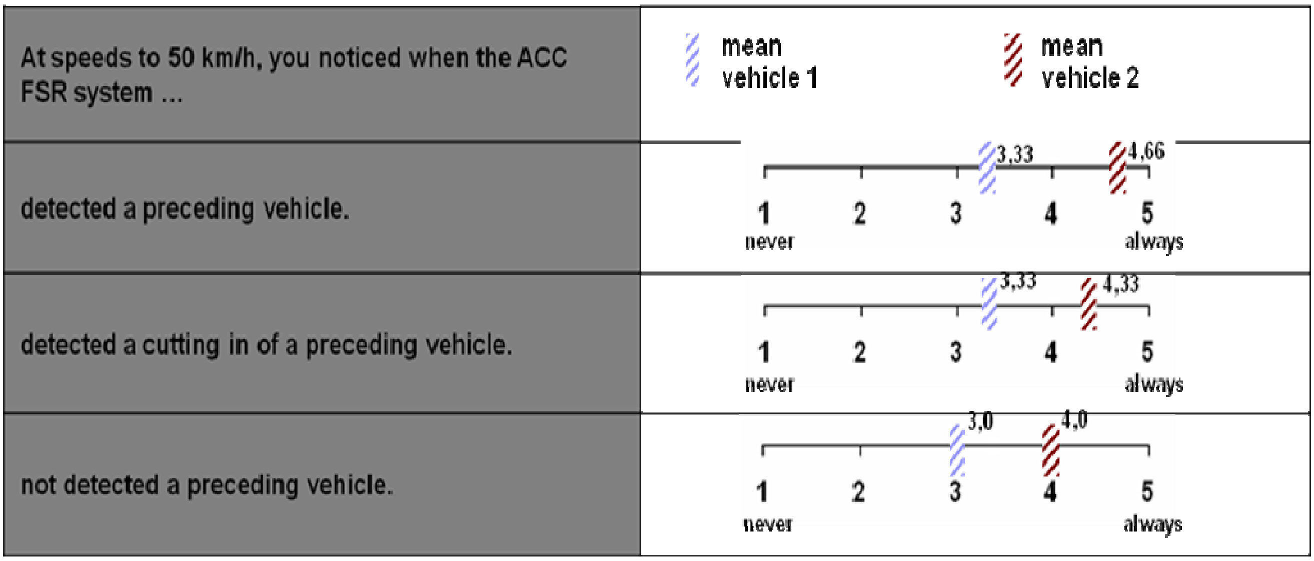

Figure 3: Subjective data for the comparison of two different full speed ACC systems (Vehicle 2 was equipped with a head up display for presenting information about the actual status of the ACC system)

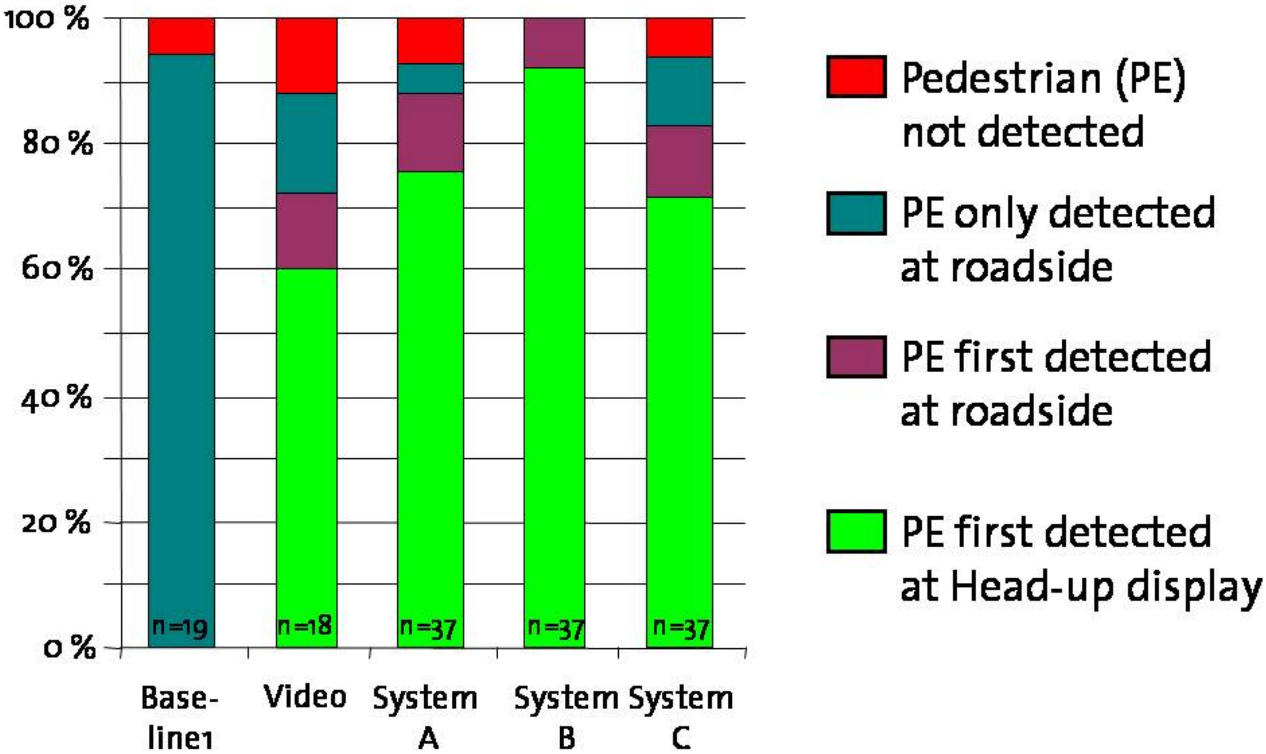

Figure 4: Percentage of detected pedestrians depending on the system used for information presentation (Baseline 1: no night vision system, Video: no marking of pedestrians, System A: Marking of pedestrians, System B: Temporarily presentation of information; System C: Abstract presentation of detected pedestrians)

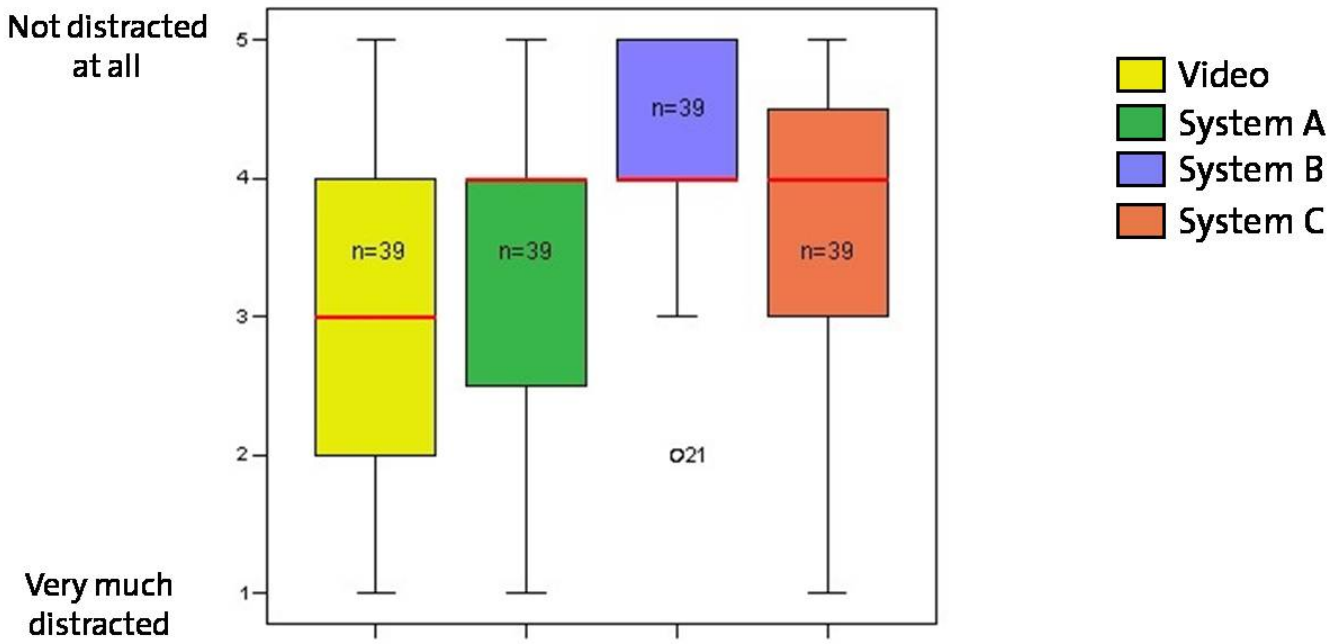

Figure 5: Degree of distraction depending on the system used for information presentation (Video: no marking of pedestrians, System A: Marking of pedestrians, System B: Temporarily presentation of information; System C: Abstract presentation of detected pedestrians). 1-very much distracted; 5 – not distracted at all

HMI FOR NIGHT VISION SYSTEM WITH PEDESTRIAN DETECTION- Still many accidents with personal injury occur on country roads in darkness. So several systems had been developed and are in application that supports the driver to detect pedestrians in darkness.

A study at the Institute of Ergonomics of Darmstadt University of Technology had been conducted to compare the HMI design of different night vision systems with pedestrian detection [11]. Three different ways of presenting a pedestrian to the driver (Version A: video always present; Version B: temporary video; Version C: abstracted presentation of pedestrians) had been compared to driving with no night vision system (Baseline).

By using an eye tracking system the glance behaviour of drivers had been examined. 37 test persons participated in the study (two different categories with respect to age: 25-40 years and 50-65 years).

All systems had been evaluated in studies on public roads and within a controlled field situation (driving on a test track on a former airport) during evening and night time.

From the results of the studies it can be shown that pedestrians are observed earlier when drivers used a night vision system (see figure 4). The additional marking of pedestrians improves the recognition of pedestrians significantly.

A temporarily presentation of information only when pedestrians are detected (System B) showed best results (no pedestrians had been overlooked).

So an important result of the studies concerning night vision systems is that those systems can support drivers in difficult driving situations (in this case driving with limited visibility). But it is not enough to introduce such a system into an automobile without caring about the design of the HMI for this system. An adequate HMI design enhances the performance of the system.

Looking at the performance of a driver-vehicle system that is equipped with a night vision system is one aspect of the HMI design. Another aspect refers to the additional problems that might emerge because of an inadequate HMI design.

One of these additional problems is the distraction that drivers will experience caused by the HMI of night vision systems. In figure 5 the results of a subjective questioning while driving are presented.

It can be seen that presenting information about the external situation via a pure video system that is active all the time leads to high degree of distraction. On the contrast systems with a temporarily presentation of information (e.g. only when a pedestrian is detected) are followed by low levels of distraction.

NEW WAYS OF INTERACTION

The already presented studies concentrated on ADAS that are perceivable for the drivers by using visual HMI. The consequence of designing more and more HMI for ADAS that refer to the visual or acoustic input channel of humans is an overload of these channels (it should not be forgotten that these channels are primarily used for the driving task!).

So consequently it seems to be appropriate to introduce (semi-)autonomous systems as a special way of safe and pleasurable interaction with automobiles. With an adequate, user-centered HMI design it might be possible to expand the characteristics of drivers and to cope with problems that would be nearly unsolvable if drivers do not have any support.

Following a study will be presented concerning the design of interaction modes for an assistance system for automated steering and braking. It was one result of this study that drivers are positively surprised if a semi-autonomous system can help managing dangerous situations and those systems are highly accept if drivers experience their functionality.

INTERACTING WITH A SEMI-AUTONOMOUS VEHICLE- A project called PRORETA was conducted at the Darmstadt University of Technology (Institute of Automated Control, Chair of Automotive Engineering and Institute of Ergonomics) in cooperation with the automotive supplier CONTINENTAL. The aim of this study was the development of a driver assistance system for an accident avoiding vehicle that will recognize obstacles on the roadway and, if the driver does not react, will execute automatic braking- or steering- manoeuvres.

The following questions are of importance regarding the integration of the assistance system into the control loop driver-vehicle-environment:

- How do drivers react to fully automatic braking- and steering-interventions?
- Will drivers accept such interventions?
- Which freedom should the driver have to overcontrol the assistance system?

Driving tests were performed to answer those questions and to investigate the reactions of "Normal Drivers" to automatic interventions in case of suddenly appearing obstacles.

<u>Testing conditions - </u>The test persons were instructed to drive a course marked by pylons, where an obstacle appeared suddenly out of one of the pylons.

Video captures, glance behaviour data, vehicle data (e.g. accelerations, steering wheel angles, pedal positions) and subjective assessment of the drivers' acceptance were recorded.

The evaluation was carried out in view of reaction times, pedal- and steering wheel activities, collisions with the obstacle, gaze behaviour, facial expressions and acceptance.

Overall the study comprehends three test series:

- Test series 1: Driver behaviour in the event of a suddenly appearing obstacle – without automatic intervention
- Test series 2: Driver behaviour in the event of a suddenly appearing obstacle – with an automatic emergency braking intervention
- Test series 3: Driver behaviour in the event of a suddenly appearing obstacle – with an automatic steering intervention

<u>Results - </u>In case of the suddenly appearing obstacle more than 1/3 of the test persons did neither brake nor steer. They just did nothing to avoid a collision. In this field, there exists an obvious potential for accident avoidance by an automatic intervention. In general, various driver assistance levels are possible in the range of accident avoidance (see figure 6).

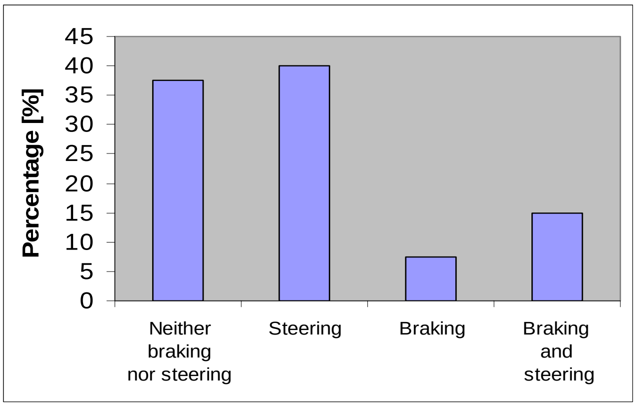

Figure 6: Drivers' steering and braking reactions to the sudden obstacle ([12])

They range from a pure warning in a critical situation to a fully automatic intervention. The driver should have the control over the vehicle as long as possible. So it is reasonable to design a stepwise increasing assistance level depending on the remaining time (time-to-collision). Hence an automatic intervention is advisable in the last moment that is feasible regarding the driving dynamics, when all other strategies failed or the critical situation came too suddenly. Here the driver should have no possibility to overcontrol the vehicle, as it is not sure, that he will act in a suitable way.

In 88 % of the automatic braking interventions, the drivers pressed down the accelerator pedal due to the inertia forces induced by the sudden deceleration.

In case of fully automatic steering interventions more than 50 % of the drivers had the feeling to have initiated the evading manoeuvre by themselves – the automatic steering actions conformed to the expectations of the drivers (see figure 7).

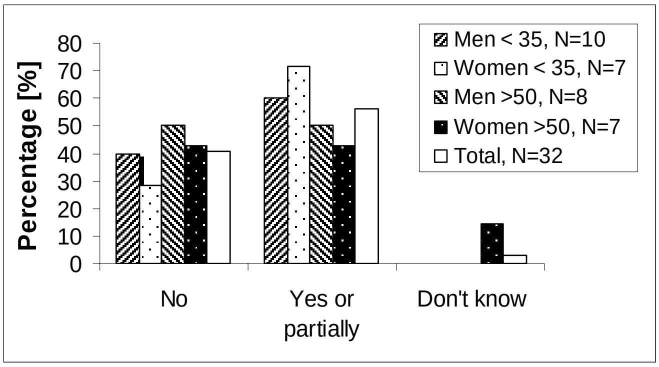

Figure 7: Answers of the test persons to the question: “Did the vehicle attend your steering orders?” ([12])

Overall there was a high acceptance of the automatic braking system. Concerning the automatic steering system, the acceptance was clearly less. Although there were no vehicles on the opposite lane, many test persons had scruples and a bad feeling, when the automatic steering system took over the control.

CONCLUSION

Not at least because of an increasing traffic density in many global areas the driving task has become more complex. This increasing complexity of the driving task and the demand for a decreasing number of accidents is giving reasons for the development of assistance systems to support drivers.

To enhance the overall performance of the driver-vehicle system it is necessary that each partner in the system knows about the functioning of all system elements.

Different data is recorded and evaluated while driving (e.g. ankle of steering wheel, position of brake or gas pedal) to provide the assistance systems with information about the functioning of the driver. The understanding of the functioning of assistance systems is given to drivers with the help of an adequate HMI design of those systems.

But it is not enough to design HMI for future automobiles only with a focus on systems functionality. Driving always was and still will be an emotional experience.

It seems contradictory to design safe and at the same time joyful HMI for automobiles. And there is indeed no joy-of-use if HMI for example for advanced driver assistance systems are difficult to understand and distract drivers form the primary driving task.

But according to [13] HMI are well accepted and pleasurable for their users if one of their key attributes is simplicity. This is especially true for designing HMI for automobiles. Studies concerning the HMI for ACC systems and night vision systems show the positive influence of easy-to-use HMI on the system performance. Those HMI are also the ones with the best acceptance by drivers.

Further attributes of HMI for automobiles that could enhance the joy-of-use and that are not in conflict with the demand of safety are:

- Allowing drivers to have new sensual experiences when using HMI in automobiles by integrating unusual materials or new interaction principles (e.g. touch screen technology).

- Bringing technologies into automobiles that are up-to-date in non automotive context (e.g. airplanes) but that are still unused in automobiles (e.g. voice control). Those technologies increase the joy-of-use of HMI because of their newness and the surprising effect. But it must be assured that the new technologies are really supporting the driving task.

- Supporting drivers in a way that they are not really aware of the support (which is an attribute of a real good assistance). This might involve the ability of assistance systems to take over complete operations so that drivers will have the feeling that the performance of a (semi)-autonomous system is exactly what they would have done. This new era of human-machine cooperation might also be an era of joyful driving.

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